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ERROR ANALYSIS OF PRESENTED AREA COMPUTATION TECHNIQUES

Final Report

R.B. Smith

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Prepared for

JOINT LOGISTICS COMMANDERS
JOINT TECHNICAL COORDINATING GROUP
ON
AIRCRAFT SURVIVABILITY

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FOREWORD

This report summarizes results of tests performed by Raytheon Company, Sudbury, MA, for Aeronautical Systems Division, Deputy for Engineering, Wright-Patterson Air Force Base, OH, under contract F33615-73-C-0678. The work was performed between May and December 1974, and J. H. Howard was project engineer.

The work was sponsored by JTCG/AS as part of the 3-year TEAS (Test and Evaluation, Aircraft Survivability) program. The TEAS program was funded by DDR&E/ ODDT&E. The effort was conducted under the direction of the JTCG/AS Survivability Assessment Subgroup as part of TEAS element 5.1.7.1/3, *Component and Aircraft Assessment.*

This report uses the rectangular and ellipsodial projection techniques to convert six cardinal views into 26 views for attrition modeling purposes. Also included are presented area computation techniques.

NOTE

This technical report was prepared by the Vulnerability Assessment Subgroup of the Joint Technical Coordinating Group on Aircraft Survivability in the Joint Logistics Commanders' organization. Because the Services' aircraft survivability development programs are dynamic and changing, this report represents the best data available to the subgroup at this time. It has been coordinated and approved at the JTCG subgroup level. The purpose of the report is to exchange data on all aircraft survivability programs, thereby promoting interservice awareness of the DOD aircraft survivability program under the cognizance of the Joint Logistics Commanders. By careful analysis of the data in this report, personnel with expertise in the aircraft survivability area should be better able to determine technical voids and areas of potential duplication or proliferation.

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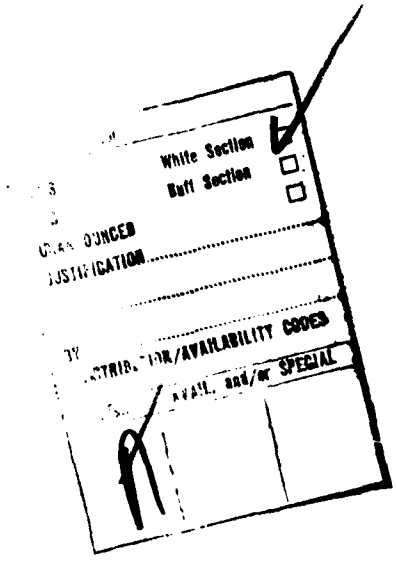

INTRODUCTION

Requirements for JTCG/AS test and evaluation resulted in A_V[1] (vulnerable area) data being developed for only six cardinal views. These views are defined using the positive and negative directions along the axes through the aircraft centroid, as shown in Figure 1. Six views are insufficient for attrition modeling purposes. For example, P001[1] required 26 views which must be obtained by projection of the six cardinal views. This can be accomplished using either an R (rectangular) or E (ellipsodial) projection technique. To determine the better technique, Raytheon was tasked by ASD (Aeronautical Systems Division), Directorate of Systems Engineering (ASD/ENFTV), Wright-Patterson Air Force Base, OH, to evaluate the relative merits of the two techniques. The scope was later expanded to include an examination of the A_p (presented area) computation techniques used in the P001, SIMFIND 2[2], and EVADE II[3] attrition models.

ANALYSIS

The 26 A_p views required for P001 shown in Figure 1 are obtained from seven principal views. Only the octrant is shown; spatial relationships of the points in the other quadrants are identical. Due to aircraft symmetry and interest in A_p to projectiles only, the 26 views can be reduced to seven principal views (Table 1 and Figure 1), since the remaining 19 are mirror images. Equivalencies are listed in Table 2.

The seven views can be approximated using the six cardinal views (footnote 1) and are calculated using R and E projections as shown in Eq. (1) and (2):

$$A_{p_R} = A_F |\vec{F}\cdot\vec{D}| + A_S |\vec{S}\cdot\vec{D}| + A_T |\vec{T}\cdot\vec{D}| \quad (1)$$

$$A_{p_E} = \sqrt{(A_F\,\vec{F}\cdot\vec{D})^2 + (A_S\,\vec{S}\cdot\vec{D})^2 + (A_T\,\vec{T}\cdot\vec{D})^2} \quad (2)$$

where:

$\vec{D}$ = direction of shot unit vector
$\vec{F}$ = front of aircraft unit vector
$\vec{S}$ = side of aircraft unit vector
$\vec{T}$ = top of aircraft unit vector

---

[1] Air Force Armament Test Laboratory. *P001 Anti-Aircraft Artillery Simulation Computer Program*, Eglin AFB, FL, AFATL, November 1972. (Volume II, publication UNCLASSIFIED.)

[2] Armament Systems, Inc. *SIMFIND 2 Digital Simulation for Aircraft Survivability*, Anaheim, CA, ASE, March 1973. (Volume II, publication UNCLASSIFIED.)

[3] *EVADE II, A Simulation Program for: Evaluation of Air Defense Effectiveness*, February 1973. (Volume II, publication UNCLASSIFIED.)

Using the definition of ϕ (degrees latitude) and ψ (degrees longitude) from Figure 1, Eq. (1) becomes:

$$A_{p_R} = A_F |\sin\phi \cos\psi| + A_S |\sin\phi \sin\psi| + A_T |\cos\phi| \quad (3)$$

and Eq. (2) becomes

$$A_{p_E} = \sqrt{(A_F \sin\phi \cos\psi)^2 + (A_S \sin\phi \sin\psi)^2 + (A_T \cos\phi)^2} \quad (4)$$

The areas associated with the seven principal views were calculated, using Eq. (3) and (4), for the A-4, A-7, A-10, and OV-10. ASD/ENFTV provided A_p data for each of the aircraft which served as the standard of comparison. Using the SHOTGEN[4] descriptions of the A-4, A-7, and OV-10, the seven principal aspects were plotted and the areas measured by a Hewlett-Packard model 9864A digitizer. A similar method was used for the A-10. Table 3 contains the areas calculated using: (1) the assumed correctly measured areas; (2) the R and E projections; and (3) the resulting percentage of error. For examples of projection, refer to the appendix.

P001 accepts 26 views as input and uses an L (linear) interpolation technique to develop A_p data for all nonprincipal views (see footnote 1). SIMFIND 2 and EVADE II accepts the A_V data for the six cardinal views as input and, using either an R or E projection, approximate the A_p for each point of interest. (See footnotes 1 and 2.)

The computation schemes of the three attrition models were evaluated by computing the A_p for a number of points on the total viewing sphere and comparing these with a baseline case. The A_p were calculated for all (ϕ, ψ) combinations on the viewing sphere where:

ϕ = n (15 degrees) with $0 \leq \phi \leq 180$ degrees and n = 0,1,2. . .12

ψ = m (15 degrees) with $0 \leq \psi < 360$ degrees and m = 0,1,2. . .24

The baseline case was constructed using a binomial curve fit through the *correct* principal areas for a constant ϕ or ψ.

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[4] *SHOT Generator Computer Program*, July 1970. (Volume II, publication UNCLASSIFIED.)

A FOM (figure of merit) was devised to facilitate the evaluation and is defined by:

$$FOM = \frac{100}{N} \sum_{i=1}^{N} \frac{(A_i - A_{i_B})}{A_{i_B}} \sin \phi \qquad (5)$$

where:

A_i = computed value

A_{i_B} = from binomial fit to actual areas

N = number of views

The scheme used for selecting points on the viewing sphere did not produce a uniform distribution.

When ϕ in Figure 1 is less than 90 degrees, the space angle between any two viewing points with the same value for ϕ is smaller than the value of $\Delta\psi$ used to generate them. The angle formed by these two points is equal to $\Delta\psi \sin \phi$. To correct for the nonuniformity of density, the errors used to obtain the FOM were multiplied by the weighting factor, $\sin \phi$. These data are presented in Table 4.

A_p were calculated and FOM determined for each aircraft. A_p for each point were obtained for five cases: three used the P001 method and two used R and E projection. The EVADE II model computes either R or E projections while the SIMFIND 2 model computes both.

The 26 views used by the L method were the measured and R and E projection approximated areas.

CONCLUSIONS

Comparison of R and E projection (Table 3) indicates that the amount of error for each aspect is aircraft dependent. The E projection appears to be better for the A-4, A-7, and A-10. The R projection yields more accurate results for the OV-10, which has more rectangular profiles. For the A-10, which is somewhat *boxy*, the E projection yields only slightly better results than R, strengthening the implication that errors are introduced as a result of aircraft shape[5].

[5] Air Force Institute of Technology. *The Effect of Shape on Aircraft Vulnerable Area and Probability of Kill for an Anti-Aircraft Simulation*, by J. P. VerStreate, AFIT, March 1974. (GA/MC/74-19, publication UNCLASSIFIED.)

The evaluation of the techniques for computing A_p (see Table 4) by a FOM yielded different results from those discussed previously. In Table 4, the 26 L measured was best for the A-4, A-7, and A-10, while the 26 R was better for the OV-10. In general, the amount of error using 26-view methods was less than the other methods.

Generation of the 26 views for P001 from the six cardinal views requires use of the FOM in selecting the appropriate approximation technique. That is, the seven prime areas should be generated using both R and E projection and the FOM computed for each. In this way the best method is selected for the particular aircraft of interest.

SIMFIND 2 and EVADE II methods require computing a FOM to determine whether R or E projection is more accurate for each type aircraft in the program.

RECOMMENDATIONS

›mplete study should be undertaken for a larger variety of aircraft using act· ·rmining the FOM rather than a binomial curve fit.

Based on the results of this study, the A_p computation methods used in SIMFIND 2 and EVADE II should be reviewed to determine techniques to improve accuracy.

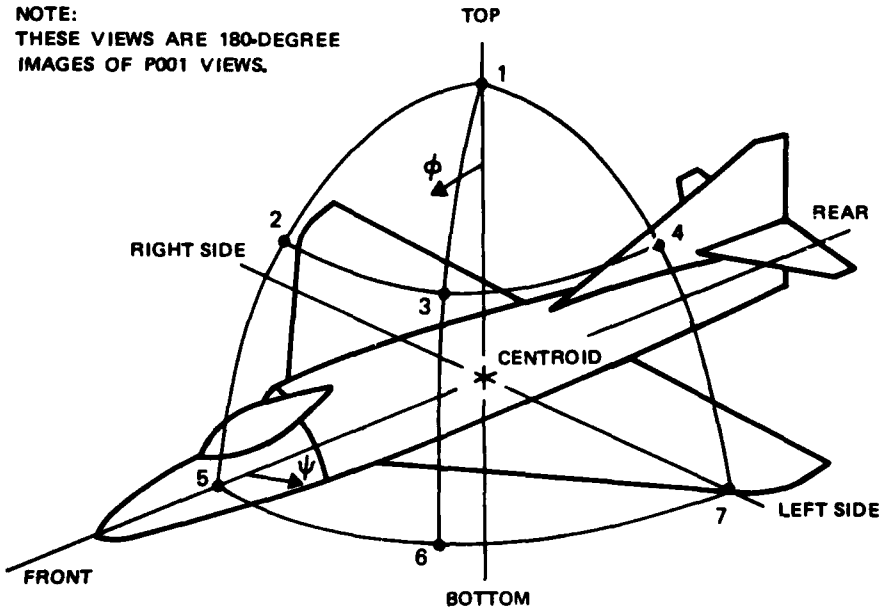

Figure 1. Seven Principal Views.

Table 1. 26 Required Views.

View	ϕ, deg	ψ, deg	View	ϕ, deg	ψ, deg
1	0	0	14	90	180
2	45	0	15	90	225
3	45	45	16	90	270
4	45	90	17	90	315
5	90	0	18	135	0
6	90	45	19	135	45
7	90	90	20	135	90
8	45	135	21	135	135
9	45	180	22	135	180
10	45	225	23	135	225
11	45	270	24	135	270
12	45	315	25	135	315
13	90	135	26	180	0

Table 2. Mirror Image Equivalencies of Principal Views.

View	Principal		Equivalent	
	ϕ, deg	ψ, deg	ϕ, deg	ψ, deg
1	0	0	180	0
2	45	0	135	0
			45	180
			135	180
3	45	45	135	45
			45	135
			135	135
			45	225
			135	225
			45	315
			135	315
4	45	90	135	90
			45	270
			135	270
5	90	0	90	180
6	90	45	135	45
			225	45
			315	45
7	90	90	90	270

Table 3. Prime Area Calculations.

View	Measured[a]	R		E	
		Approximation	% error	Approximation	% error
		A-4			
1	33.77	33.77	0.0	33.77	0.0
2	24.76	27.09	9.4	24.09	-2.7
3	24.21	36.25	49.7	26.03	5.5
4	29.07	38.17	31.3	27.83	-4.3
5	4.54	4.54	0.0	4.54	0.0
6	15.26	17.50	14.7	14.65	-4.0
7	20.21	20.21	0.0	20.21	0.0
		A-7			
1	53.48	53.48	0.0	53.48	0.0
2	39.01	42.08	7.7	38.05	-2.5
3	40.01	57.29	43.2	41.36	3.4
4	48.82	61.14	25.2	44.43	-9.0
5	5.96	5.96	0.0	5.96	0.0
6	24.37	27.54	13.0	23.71	-2.7
7	32.99	32.99	0.0	32.99	0.0
		A-10			
1	77.94	77.94	0.0	77.94	0.0
2	62.81	65.63	4.5	56.11	-10.7
3	65.26	75.62	15.9	57.13	-12.5
4	65.39	73.54	12.5	58.13	-11.1
5	14.88	14.88	0.0	14.88	0.0
6	23.34	29.00	24.2	21.26	-8.9
7	26.13	26.13	0.0	26.13	0.0
		OV-10			
1	40.84	40.84	0.0	40.84	0.0
2	29.50	34.39	16.6	29.40	-0.3
3	36.66	40.19	9.6	30.07	-18.0
4	39.95	39.36	-1.5	30.72	-23.1
5	7.80	7.80	0.0	7.80	0.0
6	15.52	16.00	3.1	11.85	-23.7
7	14.83	14.83	0.0	14.83	0.0

[a] Assumed correct

Table 4. Weighted FOM.

Method	A-4	A-7	A-10	OV-10
26 L measured	-1.2	-1.8	-4.0	-4.9
26 L R	15.6	12.6	4.6	-0.6
26 L E	-1.4	-3.1	-10.5	-14.8
6 R	22.6	19.3	10.5	5.0
6 E	-3.1	-4.6	-12.4	-16.6

APPENDIX

Equations 3 and 4 for R and E projection are as follows:

$$A_{p_R} = A_F |\sin\phi \cos\psi| + A_S |\sin\phi \sin\psi| + A_T |\cos\phi|$$

$$A_{p_E} = \sqrt{(A_F \sin\phi \cos\psi)^2 + (A_S \sin\phi \sin\psi)^2 + (A_T \cos\phi)^2}$$

Using one of the seven principal A_p areas, the A-7 has front, side, and top areas of 5.96, 32.99, and 53.48 respectively. For the view between the side and top ϕ = 45 and ψ = 90.

$$A_{p_R} = 5.96 |\sin 45 \cos 90| + 32.99 |\sin 45 \sin 90| + 53.48 |\cos 45|$$

$$= 0 + 23.327 + 37.816 = 61.14$$

$$A_{p_E} = \sqrt{(5.96 \sin 45 \cos 90)^2 + (32.99 \sin 45 \sin 90)^2 + (53.48 \cos 45)^2}$$

$$= \sqrt{0^2 + (32.327)^2 + (37.816)^2} = 44.43$$

For A_p computation method comparison where ϕ = 60 deg, ψ = 30 deg and for the L interpolation:

ϕ = 45 deg, ψ = 0 deg	39.01
ϕ = 90 deg, ψ = 0 deg	5.96
ϕ = 45 deg, ψ = 45 deg	40.01
ϕ = 90 deg, ψ = 45 deg	24.36

$F_\phi = \phi/45 = 60/45 = 1.333$ $\qquad$ $F_\psi = \psi/45 = 30/45 = 0.667$

$I_\phi = F_\phi = 1.333 = 1$ $\qquad$ $I_\psi = F_\psi = 0.667 = 0$

$\Delta_\phi = F_\phi - I_\phi = 1.333 - 1 = 0.333$ $\qquad$ $\Delta_\psi = F_\psi - I_\psi = 0.667 - 0 = 667$

$$A_{p_L} = (1-\Delta\phi)(1-\Delta\psi)A(45,0) + \Delta\psi A(45,45) + \Delta\phi(1-\Delta\psi)A(90,0) + \Delta\psi A(90,45)$$

$$= 0.667(0.333(39.01) + 0.667(40,01))$$

$$+ 0.333(0.333(5.96) + 0.667(24.36))$$

$$= 0.667(39.677) + 0.333(18.227) = 32.53$$

For R projection:

$$A_{p_R} = 5.96|\sin 60 \cos 30| + 32.99|\sin 60 \sin 30| + 53.48|\cos 60|$$
$$= 4.470 + 14.285 + 26.74 = 45.50$$

For E projection:

$$A_{p_E} = \sqrt{(5.96 \sin 60 \cos 30)^2 + (37.99 \sin 60 \sin 30)^2 + 53.48 (\cos 60)^2}$$
$$= \sqrt{(4.470)^2 + (14.285)^2 + (26.74)^2} = 30.64$$

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